

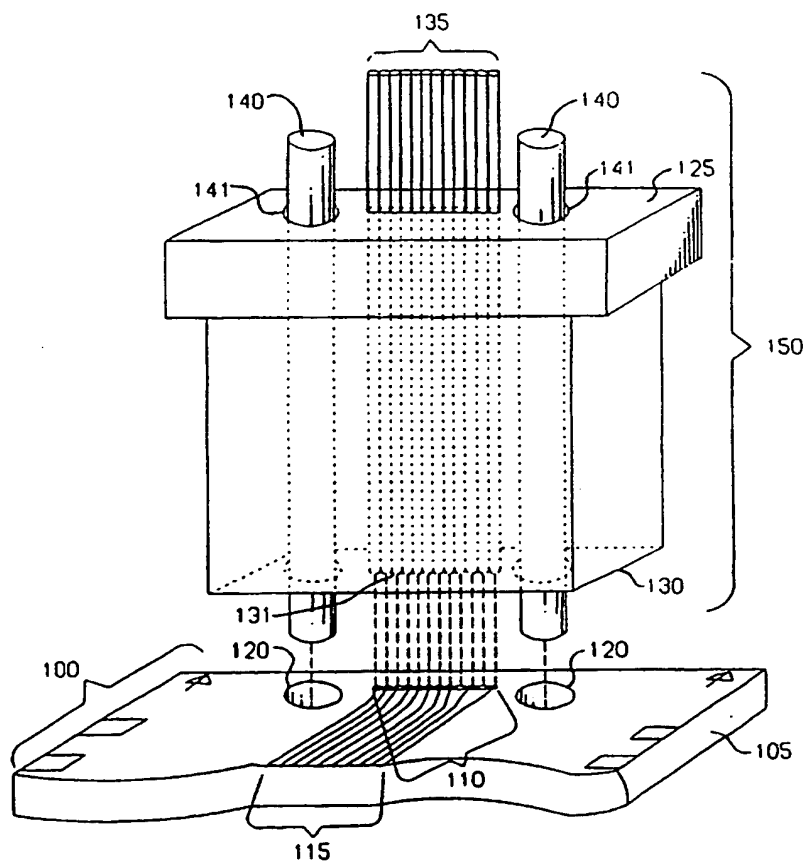


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification⁵ : G02B 6/00, 6/12, 6/26, 6/36, 6/42, H01L 39/02, 21/70, B29D 11/00	A1	(11) International Publication Number: WO 94/28448 (43) International Publication Date: 8 December 1994 (08.12.94)
(21) International Application Number: PCT/US94/05749 (22) International Filing Date: 23 May 1994 (23.05.94) (30) Priority Data: 066,757 24 May 1993 (24.05.93) US (71) Applicant: BANDGAP TECHNOLOGY CORPORATION [US/US]; 325 Interlocken Parkway, Broomfield, CO 80021 (US). (72) Inventors: SWIRHUN, Stanley, E.; 1471 Cassin Street, Boulder, CO 80303 (US). UCHIDA, Toshi, K.; 301 E. Malley Drive #50, Northglenn, CO 80233 (US). (74) Agents: MORRIS, Francis, E. et al.; Pennie & Edmonds, 1155 Avenue of the Americas, New York, NY 10036 (US).		(81) Designated States: AU, BB, BG, BR, BY, CA, CN, CZ, FI, GE, HU, JP, KG, KR, KZ, LK, LV, MD, MG, MN, MW, NO, NZ, PL, RO, RU, SD, SI, SK, TJ, UA, UZ, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: PARALLEL OPTICAL INTERCONNECT**(57) Abstract**

An optical interconnect is disclosed that couples multiple optical fibers (135) to an array of optoelectronic device. The interconnect includes a multiple optical fiber connector (150) and an optoelectronic board (100). The multiple fiber connector (150) can be mechanically attached to or detached from the board (100).



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgyzstan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SI	Slovenia
CI	Côte d'Ivoire	KZ	Kazakhstan	SK	Slovakia
CM	Cameroon	LI	Liechtenstein	SN	Senegal
CN	China	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
CZ	Czech Republic	LV	Latvia	TJ	Tajikistan
DE	Germany	MC	Monaco	TT	Trinidad and Tobago
DK	Denmark	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	US	United States of America
FI	Finland	ML	Mali	UZ	Uzbekistan
FR	France	MN	Mongolia	VN	Viet Nam
GA	Gabon				

PARALLEL OPTICAL INTERCONNECTFIELD OF THE INVENTION

5 This invention relates to optical interconnects and, more particularly, to optical interconnects that couple multiple optical fibers to arrays of integrally formed optoelectronic devices.

10 BACKGROUND OF THE INVENTION

 Optical fiber technology has been widely utilized in today's telecommunication network. It is also the foundation of a future generation of telecommunication technology which is predicted to
15 revolutionize the way people exchange or obtain information.

 One important aspect of optical fiber technology is the interconnection of optical fibers to optoelectronic devices such as semiconductor lasers,
20 photo-detectors, etc, wherein the optoelectronic devices either receive optical radiation from the optical fibers or the optoelectronic devices emit optical radiation into the fibers. A good optical interconnect between an optical fiber and an
25 optoelectronic device requires high coupling efficiency (i.e. low loss of light from the coupling), ease of making the coupling, and low cost for making such an interconnect.

 The conventional method for coupling an
30 optical fiber to an optoelectronic device is by active alignment. For example, to couple a semiconductor laser to an optical fiber by active alignment, the laser is first turned on to emit optical radiation. A coupling end of the optical fiber is then placed near
35 a light emitting surface of the laser to receive optical radiation, and a photodetector is placed at

the other end of the fiber to detect the amount of optical radiation that is coupled into the fiber. The position of the coupling end of the fiber is then manipulated manually around the light-emitting surface of laser until the photodetector at the other end of the fiber detects maximum optical radiation. Optical epoxy is then applied to both the laser and the coupling end of the fiber so as to permanently maintain the optimized coupling.

A photo-detector can be similarly coupled to an optical fiber by shining laser light into one end of the fiber and manually adjusting the position of the other end of the fiber that is to be coupled to the detector until the detector's electrical response to the optical radiation reaches a maximum. Optical epoxy is then applied to attach the fiber to the detector.

Because the dimensions of the light-emitting surface of a semiconductor laser and the cross-section of an optical fiber are very small, e.g. on the order of $10\mu\text{m}$ for single mode fiber, coupling a semiconductor laser to an optical fiber is a task that is usually time-consuming and requires expertise and experience. As for coupling an optical fiber to a photo-detector, even though one may increase the size of the detector to make such coupling easier, increasing the detector size undesirably increases the parasitics of the detector and thus compromises the detector's operating speed and frequency response.

One problem of the above-described optical interconnect is that the alignment between the fiber and the optoelectronic device may suffer misalignment under thermal strain. Such thermal strain occurs when the temperature of the interconnect increases due to the heat generated by the optoelectronic device, the circuits for driving the device, or by various other factors such as the nearby electronic components.

It is also not practical to apply the above-described method of active alignment to couple multiple optical fibers to an array of optoelectronic devices that are monolithically formed on a semiconductor chip because the array normally contains a large number of devices that are closely spaced. However, it would be very useful to couple such an array of photo-emitters to such an array of photo-detectors via multiple optical fibers in applications such as local area networks (LANs) which require the coupling of signals in parallel.

It is therefore an object of this invention to provide optical interconnects that mechanically couple multiple optical fibers to arrays of integrally formed optoelectronic devices.

SUMMARY OF THE INVENTION

The present invention is an optical interconnect for coupling multiple optical fibers to an optoelectronic device array.

In a first embodiment of the invention, the optical interconnect comprises a multiple optical fiber connector coupled with an optoelectronic board.

The multiple fiber connector comprises a holder having at least one planar surface, a plurality of optical fibers attached to the holder, each fiber having a coupling end abutting the first surface so as to expose the coupling end for receiving or transmitting optical radiation, the first ends of the fibers forming a fiber array, and guiding means disposed in the holder at predetermined positions with respect to the fiber array.

The optoelectronic board comprises an array of optoelectronic devices that are monolithically formed on a semiconductor chip in substantially the same pattern as the fiber array. The board further

comprises aligning means formed on the chip at substantially the same predetermined positions with respect to the array of optoelectronic devices as the guiding means are positioned relative to the fiber array.

5

The fiber connector is coupled to the optoelectronic board by aligning and engaging the guiding means into the aligning means, whereby the optoelectronic device array is aligned with the optical fiber array, and whereby each optoelectronic device is coupled to an optical fiber. Preferably, the guiding means are guiding pins and the aligning means are aligning holes formed in the chip.

10

The optoelectronic devices may be photo-emitters which emit optical radiation into the fiber array or photo-detectors which receive optical radiation transmitted from the fiber array.

15

In a second embodiment, the optical interconnect comprises a multiple optical fiber connector and an optoelectronic board. The fiber connector is the same as that of the first embodiment.

20

The optoelectronic board comprises a substrate having a first surface and first aligning means, a semiconductor chip mounted on the first surface of the substrate, and an array of optoelectronic devices monolithically formed on the chip. The optoelectronic devices are arranged on the chip in substantially the same pattern as the fiber array. The optoelectronic board further comprises a second aligning means for aligning the optoelectronic device array to the first aligning means. The first aligning means are disposed at substantially the same predetermined positions with respect to the optoelectronic device array as the guiding means are positioned relative to the fiber array.

25

30

35

The connector is coupled to the optoelectronic board by aligning and engaging the

guiding means into the aligning means, whereby the optoelectronic device array is aligned with the optical fiber array, and whereby each optoelectronic device is coupled to a fiber. Preferably, the guiding means are guiding pins and the aligning means are
5 aligning holes formed in the substrate. Again, the optoelectronic devices may be photo-emitters or photo-detectors.

This invention reduces misalignment due to thermal strain caused by thermal expansion mismatch
10 between the different materials that are used in the interconnect. This is achieved by anchoring the optical fiber assembly to the locations of the guiding pins.

In a third embodiment of the invention, an
15 optical interconnect comprises an optical fiber and a vertical cavity surface emitting laser (VCSEL) coupled to a coupling end of the fiber.

The optical fiber comprises a core and a cladding layer surrounding said core. The core at the
20 coupling end of the fiber is recessed so as to form a rimmed structure, wherein the rim comprises substantially the cladding layer.

The VCSEL comprises a semiconductor substrate, a first mirror formed on said substrate, a
25 second mirror parallel to and disposed above the first mirror and forming with said first mirror an optical cavity that is perpendicular to the substrate, and an active region surrounded by first and second spacers disposed between said mirrors.

30 The first and second mirrors are distributed Bragg reflectors comprising a plurality of layers formed one on top of the other. The uppermost layers of said second mirror form a mesa having a diameter less than the inner diameter of the rim. The mesa
35 engages said rimmed structure so as to place a substantial portion of said mesa inside the rim. As a

result, the laser is self-aligned and the optical radiation emitted from the laser is substantially coupled into said optical fiber.

5 This interconnect reduces the misalignment due to thermal strain because the laser is embedded in the optical fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

10 These and other objects, features and advantages of the invention will be more apparent from the following detailed description in conjunction with the appended drawings in which:

Fig. 1a illustrates a three-dimensional view of a first embodiment of the optical interconnect of the present invention;

15 Fig. 1b depicts a view of surface 130 of Fig. 1a;

Fig. 2 depicts a second embodiment of the invention;

20 Fig. 3 illustrates the packaged interconnect of Fig. 2;

Figs. 4a-b illustrate an application of the optical interconnects of the present invention;

25 Figs. 5a-c depict a third embodiment of the optical interconnect of this invention; and

Figs. 6a-b illustrate an array of optical interconnects of Figs. 5a-c.

DETAILED DESCRIPTION

30 In accordance with the invention, a first embodiment of the optical interconnect of the present invention comprises a multiple optical fiber connector and an optoelectronic board. The connector comprises a holder, a plurality of optical fibers attached to
35 the holder, and guiding means. The optoelectronic board comprises an optoelectronic device array that is

monolithically formed on a semiconductor chip and aligning means defined on the chip. The optical fibers are coupled to the optoelectronic device array by mechanically engaging the connector's guiding means to the aligning means of the board.

5 Fig. 1a illustrates a preferred embodiment of the optical interconnect. The preferred embodiment comprises an optical fiber connector 150 and an optoelectronic board 100.

10 Optical fiber connector 150 comprises a holder 125 having a planar surface 130, a plurality of optical fibers 135 embedded in the holder, and two guiding pins 140 slideably mounted in two cylindrical tunnels 141.

15 The fibers have coupling ends 131 that vertically abut surface 130. The coupling ends of the fiber are exposed so as to receive or emit optical radiation. As depicted in the end view of surface 130 in Fig. 1b, coupling ends 131 form a one-dimensional optical fiber array 132. The distance between any two
20 fibers in the array is equal to that of any other two adjacent fibers. Preferably, the distance between centers of any two adjacent fibers is about 0.25 mm.

Tunnels 141 and pins 140 are positioned symmetrically with respect to the fiber array. The
25 positions of the tunnels and pins with respect to the fiber array are predetermined.

Optoelectronic board 100 comprises a semiconductor chip 105, a one-dimensional optoelectronic device array 110 monolithically formed
30 on the semiconductor chip, and a plurality of conducting lines 115 for contacting the optoelectronic devices. The chip contains two aligning holes 120 having approximately the same diameter as tunnel 141 for receiving the guiding pins. Advantageously, array
35 110 and aligning holes 120 of the board have substantially the same pattern as that formed by

optical fiber array 132 and tunnels 141 of the fiber connector, i.e., the distance between the centers of any two adjacent optoelectronic devices are the same as the distance between the centers of any two adjacent fibers. Thus, by simply engaging the guiding pins 140 in the tunnels of the fiber connector to the aligning holes 120 on the optoelectronic board, the optical fiber array is axially aligned to the optoelectronic device array. Each optical fiber is also aligned to a corresponding optoelectronic device.

Optical connectors similar to the one shown in Fig. 1a have been disclosed by Hayashi, et al in European Patent Application publication No. 0,226,274 which is incorporated herein by reference. The same type of optical connectors are commercially available with a tolerance on the order of $10\mu\text{m}$ between the centers of two adjacent fibers.

The optoelectronic device array and the aligning holes on the semiconductor chip are defined by well developed semiconductor processing technologies such as photolithography and chemical or reactive ion etching. Consequently, the tolerance of the device features or the aligning holes can be controlled to within the order of $10\mu\text{m}$. Combining this tolerance with the tight tolerance of the available fiber connector, this interconnect provides good coupling efficiency. It can also be easily connected or disconnected.

The optical fibers may be single mode fibers or multi-mode fibers, e.g. plastic fibers. Preferably, the optical fibers are multi-mode fibers having a core diameter ranging from 50 to $100\mu\text{m}$. Multiple mode optical fibers normally have greater core diameters than single mode optical fibers; and as a result they offer higher alignment tolerance than single mode fibers.

The optoelectronic devices may be various types of devices such as edge-emitting lasers, Super Luminescence Diodes (SLEDs), Vertical Cavity Surface Emitting Lasers (VCSELs), other surface emitting devices or photo-detectors. They may also be
5 integrated devices combining one or more devices such as the combination of VCSELs and transistors, or photo-detectors and transistors.

When the optoelectronic devices are VCSELs, the optical interconnect functions as a transmitter
10 sending optical signals into the optical fibers. Generally, the tolerance of alignment in this interconnect is in the range of 2-20 μ m. For example, each VCSEL has a diameter of approximately 20 μ m and each fiber is a multi-mode fiber having a core
15 diameter of about 62.5 μ m, the alignment tolerance is about 10 μ m.

The optical interconnect may further comprise electronic circuit means interconnected to the VCSEL array for driving and modulating the VCSELs.
20 Such electronic circuit means may be monolithically formed on the semiconductor chip, or integrated with the VCSEL array as a hybrid integrated circuit.

If the optoelectronic devices are photo-detectors formed on the semiconductor chip, the
25 optical interconnect functions as a receiver for receiving optical signals from the optical fibers. For example, if each photo-detector is a Schottky-barrier photo-detector having a diameter of approximately 100 μ m, and each fiber is a multi-mode
30 fiber having a core diameter of about 62.5 μ m, the alignment tolerance between the fibers and the detectors is about 20 μ m.

In the above-described preferred embodiment, one-dimensional arrays are used as an example.
35 However, two-dimensional arrays can also be similarly

utilized to form a two-dimensional optical interconnects.

In the second embodiment of the present invention, the optical interconnect also comprises an optical connector and an optoelectronic board. The
5 connector comprises a holder, a plurality of optical fibers attached to the holder, and guiding means. The optoelectronic board comprises a substrate, a semiconductor chip disposed on the substrate, and an
10 optoelectronic device array monolithically formed on the semiconductor chip. The optoelectronic board further comprises first aligning means formed in the substrate, and second aligning means disposed between the chip and the substrate so as to properly position the optoelectronic device array with respect to the
15 first aligning means. By mechanically aligning and engaging the guiding means of the connector to the first aligning means of the board, the optical fibers are coupled to the optoelectronic device array.

Fig. 2a depicts the preferred embodiment of
20 the optical interconnect which comprises an optical connector 150 and an optoelectronic board 101. For convenience, like elements in Figs. 2a-b are designated with the same numbers as in Fig. 1.
Optical fiber connector 150 in this embodiment is the
25 same as the optical connector in the first embodiment, and is therefore not discussed in detail here.

Optoelectronic board 101 comprises a dielectric substrate 90, a semiconductor chip 105 disposed on the substrate, a linear optoelectronic
30 device array 110 monolithically formed on the semiconductor chip, electronic circuit means 117 interconnected to the optoelectronic device array, and contact pads 108 defined at the periphery of the substrate for making contact to the circuit means.
35 The optoelectronic board further includes two aligning holes 119 formed in the substrate as first aligning

means for receiving the guiding pins. As depicted in Fig. 2b, the board further comprises second aligning means 91 formed between a second surface 95 of the semiconductor chip and a first surface 96 of the substrate. The second alignment means laterally
5 aligns the optoelectronic device array to first aligning means 119 that is formed in the substrate.

The principle of forming this optical interconnect is as follows:

The optoelectronic devices are first formed
10 on the semiconductor chip. They are arranged to form an array having the same pattern as the optical fiber array. Utilizing the well developed semiconductor technology, the positions of the optoelectronic devices can be precisely defined such that the
15 distance between centers of any two adjacent devices are the same as the distance between centers of any two adjacent fibers.

Next, aligning holes 119 in the substrate are defined by using techniques such as precision
20 laser drilling. The aligning holes have substantially the same diameters as tunnels 141 of the optical fiber connector and the distance between the centers of the two aligning holes is substantially the same as that between the tunnels. Thus, guiding pins can be
25 aligned to the aligning holes.

The optoelectronic device array is then laterally aligned to the aligning holes by utilizing the flip-chip bonding technology. As illustrated in Fig. 2b, the flip-chip bonding technology mainly
30 comprises the steps of forming a first set of metal pads 93 on first surface 96 of the substrate, the patterns having predetermined positions with respect to aligning holes 119; this is followed by depositing a layer of solder on the substrate. The solder layer
35 is then patterned by photolithography and etching to form a second set of solder patterns 94 on top of the

first set of metal patterns. A third set of metal pads 92 that is the mirror image of the first set is then defined on second surface 95 of the semiconductor chip. By utilizing infrared alignment techniques, the third set of patterns is aligned with the
5 optoelectronic device array in such a way that, if the third set is vertically aligned with the first set, the optoelectronic device array will laterally align to the aligning holes in a way such that the
10 optoelectronic device array will also be vertically aligned to the optical fiber array.

Advantageously, the third set of patterns is aligned to the first set by a self-alignment process. In the self-alignment process, the third set is first coarsely aligned with the second set. Then, heat is
15 applied to melt the solder. The melted solder is confined between the third and first metal patterns and does not flow laterally beyond the patterns. Due to the surface tension of the solder, the third set of patterns is automatically aligned to the first set of
20 patterns. When the heat is removed, the solder cools down and the self-alignment process is completed. This flip-chip technology is explained in detail by Wale et al, "Flip-Chip Bonding Optimize Opto-Ics",
IEEE Circuit and Devices, pp.25-31, Nov. 1992, which
25 is incorporated herein by reference.

Consequently, at the completion of the solder flow self-alignment process, the optoelectronic device array is laterally aligned to the aligning
30 holes in the same way as the fiber array is aligned to the guiding pins. Thus, by vertically aligning and engaging the guiding pins with the aligning holes, the fiber array is aligned with and coupled to the optoelectronic device array.

As in the case of the optical interconnect
35 of Fig. 1a, if the optoelectronic devices are VCSELs and electronic circuit means 117 are integrated

circuits for driving and modulating the VCSELs, the interconnect functions as an optical transmitter that injects optical signals into the fibers. If the optoelectronic devices are photo-detectors, the interconnect functions as an optical receiver that
5 receives optical signals transmitted through the optical fibers. The photo-detectors send electrical signals that correspond to the optical signals to the electronic circuit means which process the signals before forwarding them to other circuits such as
10 computers or processors. If the optoelectronic devices comprise both VCSELs and photo-detectors, this optical interconnect is effectively both a transmitter and a receiver.

Note that by using the solder flow self-aligning process, two or more individual semiconductor
15 chips may be aligned to one optical fiber array. In this case, the devices on one chip are coupled to some optical fibers of the fiber connector, whereas the devices on the other wafer(s) are coupled to the other
20 optical fibers. In this way, a transmitter and a receiver may be coupled to a single optical connector.

Fig. 3 illustrates the optical interconnect of Fig. 2 as mounted in a twenty-pin package 200. The fiber connector can be easily attached to or detached
25 from the optoelectronic board.

Fig. 4a illustrates the use of the optical interconnect of the present invention for board-to-board interconnect. In this application, board 400 is connected to board 410 via connectors 405 and 415.
30 Fig. 4b is an enlarged illustration of connector 405 or 415. Each of 405 or 415 comprises an optical interconnect such as the one depicted in Fig. 1a or Fig. 3. If connector 405 contains only the optical interconnect that is a transmitter and connector 415
35 contains only the optical interconnect that is a receiver, then data are transmitted only from board

400 to board 410. However, if both connector 405 and 415 include optical interconnects that have both a transmitter and a receiver, then data can be transmitted in full duplex fashion between the boards via an optical fiber ribbon.

5 In a third embodiment of invention, an optical interconnect comprises an optical fiber having a coupling end and a vertical cavity surface emitting laser coupled to the coupling end of the fiber.

10 The optical fiber comprises a core and a cladding layer surrounding the core. The core at the coupling end is recessed so as to form a rimmed structure wherein the rim comprises the cladding layer.

15 The VCSEL has a second mirror that is a distributed Bragg reflector comprising a plurality of layers formed one on top of the other. Advantageously, the outermost layers of the second mirror form a mesa that has a diameter smaller than the inner diameter of the rim. The mesa engages the
20 coupling end so as to place a substantial portion of the mesa inside the rim. The VCSEL emits optical radiation that is substantially coupled into the optical fiber.

25 Figs. 5a-c illustrate a preferred embodiment of the invention.

Specifically, Fig. 5a depicts a three-dimensional view of an optical fiber 500 and a VCSEL prior to their coupling. Fiber 500 comprises a core 505 and a cladding layer 510 surrounding the core. At
30 a coupling end 515 of the fiber, the core is recessed so as to form a rim 516 that is mainly made of the cladding layer. The VCSEL includes a mesa 555 that comprises the outermost layers of a second mirror, several underlying layers described in Fig. 5b, and a
35 contact 565 that surrounds the mesa.

Fig. 5b illustrates a cross-section view of the optical interconnect. The VCSEL comprises a first mirror 525 formed on substrate 520, a first spacer 530, an active region 535, a second spacer 540, a portion of a second mirror 545, and the mesa portion of the second mirror 555. The VCSEL further comprises contact 565 surrounding the mesa and contact 575 formed on the substrate. Additionally, there is a passivation layer 560 that protects most of the surface from the atmosphere. Preferably, the passivation layer is a SiO₂ layer. The laser further includes an annular implanted current confinement layer 550 that surrounds the active region.

Both the first and second mirrors are distributed Bragg reflectors, each comprising a plurality of layers formed one on top of the other. Additionally, each layer is a quarter-wavelength thick wherein the wavelength is the wavelength in the layer. Preferably, mesa 555 comprises dielectric layers; and layers 545 are semiconductor layers having high doping concentration so as to form low resistance contact with contact 565.

The coupling end of the fiber is firmly fixed to the upper portion of the VCSEL by an optical epoxy 570.

The optical fiber in this interconnect can be a single-mode fiber, a multi-mode fiber, or a plastic fiber.

Fig. 5c depicts the three-dimensional view of such interconnect. In this interconnect, all the optical radiation is substantially coupled into the fiber without requiring additional alignment means.

This interconnect is fabricated as follows: First, the VCSEL as illustrated in Fig. 5b is prepared, followed by the fabrication of the optical fiber with a recessed core at the coupling end. The core and the cladding layer of a glass optical fiber

are normally both made of silica. However, the core is usually doped to increase the refractive index and hence it can be selectively etched from the cladding layer by buffered hydrofluoric acid (BHF) or other acid. Next, the etched fiber is aligned to the VCSEL and the mesa of the VCSEL is fitted into the rim. Optical epoxy is then applied to the fiber and laser.

Such an interconnect can also be made in one or two dimensional arrays, wherein an array of integrally formed VCSELs is coupled to an array of optical fibers.

Figs. 6a-b illustrate an example of such an optical interconnect wherein a fiber connector 650 comprising a linear array of optical fibers is coupled to a linear array of VCSELs. Specifically, Fig. 6a depicts the VCSEL array and the fiber array prior to their coupling, whereas Fig. 6b illustrates the interconnect after their coupling.

In this embodiment, each VCSEL and each optical fiber has the same construction as those described in Fig. 5b, and thus they are not discussed in detail here. Additionally, the fiber connector 650 can be aligned and coupled to the VCSEL array by using a pair of tunnels and guiding pins in the fiber connector and aligning holes adjacent to the VCSEL array as described in the embodiments shown in Figs. 1-4.

As will be apparent to those skilled in the art, numerous modifications may be made within the scope of the invention, which is not intended to be limited except in accordance with the following claims.

Note that, throughout this specification, optical fibers may be single-mode fibers, multi-mode fibers (e.g. plastic fibers), or other types of optical fibers; an array of optoelectronic devices may be one-dimensional or two dimensional; the

optoelectronic devices may edge emitting lasers, super luminescence diodes, VCSELs, photo-detectors or any other type of optoelectronic device. They are all within the scope of this invention.

5

10

15

20

25

30

35

WHAT IS CLAIMED IS:

1. An optical interconnect comprising:
a multiple optical fiber connector
comprising:
5 a holder having a first planar surface,
a plurality of optical fibers attached to
the holder, each fiber having a first end abutting the
first surface so as to expose the first end for
receiving or transmitting optical radiation, the first
10 ends of the fibers forming a fiber array having a
first pattern, and
guiding means disposed in said holder at
predetermined positions with respect to the fiber
array; and
15 an optoelectronic board comprising:
an optoelectronic device array
monolithically formed on a semiconductor chip, said
optoelectronic device array having substantially the
same pattern as the first pattern of said fiber array,
20 and
aligning means formed on said chip, said
aligning means being disposed at substantially the
same predetermined positions with respect to said
array of optoelectronic devices as the positions of
25 the guiding means relative to said fiber array, and
said aligning means receiving said guiding
means so as to mechanically align said optoelectronic
device array with said optical fiber array, whereby
each optoelectronic device is aligned to an optical
30 fiber, said optoelectronic device emitting optical
radiation into said fiber array or receiving optical
radiation from said fiber array.
2. The interconnect of claim 1 wherein
35 said guiding means comprises two guiding pins mounted
in the holder, said pins extending through said first

planar surface of the holder, and said aligning means comprises two aligning holes, the fiber array being aligned to the optoelectronic device array by aligning and engaging said guiding pins with said aligning holes.

5

3. The interconnect of claim 2 wherein said fiber array is disposed between the two guiding pins.

10

4. The interconnect of claim 1 wherein said guiding means comprises two guiding pins mounted in the holder, said pins extending through said first surface of the holder in a direction perpendicular to said first surface, and said aligning means including two aligning holes, said fiber array being aligned to said optoelectronic device array by aligning and engaging said guiding pins with said aligning holes.

15

5. The interconnect of claim 4 wherein said fiber array are disposed between said two guiding pins.

20

6. The interconnect of claim 1 wherein the fibers form a one-dimensional array.

25

7. The interconnect of claim 1 wherein the fibers form a two-dimensional array.

8. The interconnect of claim 6 wherein the optoelectronic device array comprises a one-dimensional array of vertical cavity surface emitting lasers, each laser being axially aligned to a fiber and the fibers receiving optical radiation emitted by the lasers.

30

35

9. The interconnect of claim 8 further comprising a first electronic circuit means interconnected to said array of lasers for driving and modulating said lasers.

5 10. The interconnect of claim 8 wherein each of the optical fibers is a plastic optical fiber.

11. The interconnect of claim 8 wherein each of the optical fibers is a single-mode optical
10 fiber.

12. The interconnect of claim 8 wherein each of the optical fibers is a multi-mode optical
15 fiber.

13. The interconnect of claim 12 wherein each multi-mode optical fiber has a diameter of approximately $62.5\mu\text{m}$.

20 14. The interconnect of claim 13 wherein each of the vertical cavity surface emitting lasers has a diameter of approximately $20\mu\text{m}$.

15. The interconnect of claim 6 wherein the
25 array of optoelectronic devices comprises an one-dimensional array of photo-detectors, each photo-detector being axially aligned to an end of a fiber, and the detectors receiving optical radiation emitted
30 by the lasers.

16. The interconnect of claim 15 wherein the photo-detectors are Schottky-barrier photo-detectors.

35

17. The interconnect of claim 15 further comprising a second electronic means for receiving an electronic signal from the photo-detectors.

5 18. The interconnect of claim 16 wherein each of the optical fibers is a multi-mode optical fiber.

10 19. The interconnect of claim 18 wherein each multi-mode optical fiber has a diameter of approximately $62.5\mu\text{m}$.

15 20. The interconnect of claim 19 wherein each photo-detector has a diameter of approximately $100\mu\text{m}$.

21. An optoelectronic interconnect comprising:

20 a multiple optical fiber connector comprising:
a holder having at least one planar surface, a plurality of optical fibers attached to the holder, each fiber having a first end abutting the first surface so as to expose the first end for receiving or transmitting optical radiation, said
25 first ends of said fibers forming a fiber array having a first pattern, and

guiding means disposed in said holder at predetermined positions with respect to said fiber array; and

30 an optoelectronic board comprising:
a substrate having a first surface and first aligning means,

35 an optoelectronic device array monolithically formed on a first surface of a semiconductor chip, said optoelectronic device array having substantially the same pattern as the first

pattern of said fiber array, said chip being disposed on the substrate,

second aligning means for aligning said array of optoelectronic devices to said first aligning means,

5 said first aligning means being disposed at substantially the same predetermined positions with respect to said array of optoelectronic devices as the positions of the guiding means relative to said fiber array, and

10 said first aligning means receiving said guiding means so as to mechanically align said optoelectronic device array with said fiber array, whereby each optoelectronic device is aligned to an optical fiber, said optoelectronic device array
15 emitting optical radiation into said optical fiber array or receiving optical radiation from said fiber array.

20 22. The interconnect of claim 21 wherein said second aligning means comprises solder formed between two sets of identical metallic patterns, one formed on a second surface of the semiconductor wafer and the other formed on the first surface of the substrate.

25 23. The interconnect of claim 21 wherein said guiding means comprises two guiding pins mounted in the holder, said pins extending through said first planar surface of the holder, and said first aligning
30 means comprises two aligning holes, the fiber array being aligned to the array of optoelectronic devices by aligning and engaging said pins with said holes.

35 24. The interconnect of claim 23 wherein said fiber array is disposed between the two guiding pins.

25. The interconnect of claim 21 wherein said guiding means comprises two pins mounted in the holder, said pins extending through said first planar surface of the holder in a direction perpendicular to said first surface, and said aligning means comprises
5 two aligning holes, said fiber array being aligned to said array of optoelectronic devices by aligning and engaging said pins with said holes.

26. The interconnect of claim 25 wherein
10 said fiber array is disposed between the two pins.

27. The interconnect of claim 21 wherein the fibers form a two-dimensional array.

28. The interconnect of claim 21 wherein
15 the fibers form a one-dimensional array.

29. The interconnect of claim 28 wherein the fibers are plastic optical fibers.
20

30. The interconnect of claim 28 wherein the fibers are single mode optical fibers.

31. The interconnect of claim 28 wherein
25 each of the optical fibers is a multi-mode optical fiber.

32. The interconnect of claim 31 wherein the multi-mode optical fiber has a core diameter of
30 approximately 62.5 μ m.

33. The interconnect of claim 32 wherein the array of optoelectronic devices comprises an one-dimensional array of vertical cavity surface emitting
35 lasers, each laser being axially aligned to an end of

a fiber and the fibers receiving optical radiation emitted by the lasers.

34. The interconnect of claim 32 further comprising a first electronic circuit means
5 interconnected to the laser array for driving and modulating said lasers.

35. The interconnect of claim 34 wherein
10 each of the vertical cavity surface emitting lasers has a diameter of approximately $20\mu\text{m}$.

36. The interconnect of claim 31 wherein
15 the array of optoelectronic devices comprises an one-dimensional array of photo-detectors, each photo-detector being axially aligned to an end of a fiber, and the detectors receiving optical radiation emitted by the lasers.

37. The interconnect of claim 36 further
20 comprising a second electronic means for receiving electronic signals from said photo-detectors.

38. The interconnect of claim 36 wherein
25 ~~the photo-detectors are Schottky-barrier photo-~~ detectors.

39. The interconnect of claim 36 wherein
30 each of the optical fibers is a multi-mode optical fiber.

40. The interconnect of claim 39 wherein
35 the multi-mode optical fiber has a diameter of approximately $62.5\mu\text{m}$.

41. The interconnect of claim 40 wherein each of the photo-detectors has a diameter of approximately 100 μ m.

5 42. A method for interconnecting an optical connector to an optoelectronic board comprising the steps of:

providing a multiple optical fiber connector, said connector comprising:

10 a holder having at least one planar surface, a plurality of optical fibers attached to the holder, each fiber having a first end abutting the first surface so as to expose the first end for receiving or transmitting optical radiation, the first ends of the fibers forming a fiber array having a
15 first pattern, and

guiding means disposed in said holder at predetermined positions with respect to the fiber array;

20 providing an optoelectronic board, said board comprising:

an array of optoelectronic devices monolithically formed on a semiconductor chip, said optoelectronic devices having substantially the same pattern as the first pattern of said fiber array, and

25 aligning means formed on the chip, said aligning means being disposed at substantially the same predetermined positions with respect to said array of optoelectronic devices as the position of the guiding means relative to said fiber array; and

30 aligning and engaging said guiding means of said connector with said aligning means of said board so as to mechanically align said array of optoelectronic devices with said array of the optical fiber, whereby each optoelectronic device is aligned
35 to an end of the fiber, said array of optoelectronic devices emitting optical radiation into said fiber

array or receiving optical radiation from the fiber array.

43. A method for interconnecting an optical connector with an optoelectronic board comprising the
5 steps of:

providing a multiple optical fiber connector, said connector comprising:

a holder having at least one planar surface,
a plurality of optical fibers attached to
10 the holder, each fiber having a first end abutting the first surface so as to expose the first end for receiving or transmitting optical radiation, said first ends of said fibers forming a fiber array having a first pattern, and

15 guiding means disposed in said holder at predetermined positions with respect to said fiber array;

providing an optoelectronic board, said board comprising:

20 a substrate having a first surface and a first aligning means,

an array of optoelectronic devices monolithically formed on a first surface of a
~~semiconductor chip, said optoelectronic devices having~~
25 substantially the same pattern as the first pattern of said fiber array, said wafer being disposed on the substrate,

second aligning means for aligning said
array of optoelectronic devices to said first aligning
30 means,

said first aligning means being disposed at substantially the same predetermined positions with respect to said array of optoelectronic devices as the positions of the guiding means relative to said fiber
35 array; and

aligning and engaging said guiding means of said connector with said first aligning means so as to mechanically align said array of optoelectronic devices with said fiber array, whereby each optoelectronic device is aligned to an end of a fiber, said array of optoelectronic devices emitting optical radiation into said fiber array or receiving optical radiation emitted from said fiber array.

44. An optical interconnect comprising:
an optical fiber having a coupling end, said optical fiber comprising a core and a cladding layer surrounding said core, said core at the coupling end being recessed so as to form a structure having a rim, the rim comprising substantially the cladding layer;
and

a vertical cavity surface emitting laser comprising:

a semiconductor substrate,
a first mirror formed on said substrate, and
a second mirror disposed above and parallel to the first mirror and forming with said first mirror an optical cavity that is perpendicular to the substrate, the first and second mirrors being distributed Bragg reflectors comprising a plurality of layers formed one on top of the other, and

an active region surrounded by first and second spacers disposed between said mirror,

the uppermost layers of said second mirror forming a mesa having a diameter less than an inner diameter of the rim,

said mesa engaging said rimmed structure so as to place a substantial portion of said mesa inside the rim, and

said laser emitting optical radiation that is substantially coupled into said optical fiber.

45. The interconnect of claim 44 further comprising holding means for maintaining the relative positions between the coupling end of said optical fiber and said laser.

5 46. The interconnect of claim 45 wherein said holding means comprises epoxy applied to the exterior of the coupling end and the laser.

10 47. The interconnect of claim 44 wherein said laser further comprises a contact surrounding the mesa and formed on the layers of said second mirror that is close to the active region.

15 48. The interconnect of claim 44 wherein said fiber is a single mode fiber.

49. The interconnect of claim 44 wherein said fiber is a multi-mode fiber.

20 50. The interconnect of claim 44 wherein said mesa has a thickness of 1 to 3 μm .

25 ~~51. The interconnect of claim 44 wherein said laser further comprises an annular implanted~~
current confinement region surrounding the active region.

30 52. A parallel optical interconnect comprising:
an optical connector comprising:
a holder having a first planar surface,
a plurality of optical fibers attached to
said holder, each fiber having a coupling end abutting
the first surface so as to expose the coupling end for
35 receiving or transmitting optical radiation,

each said optical fiber comprising a core and a cladding layer surrounding said core, said core at the coupling end being recessed so as to form a structure having a rim, the rim comprising substantially the cladding layer,

5 said coupling end of the fibers forming a fiber array having a first pattern; and

 an array of vertical cavity surface emitting lasers monolithically formed on a semiconductor chip, said array having substantially the same pattern as
10 said fiber array, and each laser comprising:

 a first mirror formed on said chip, and a second mirror disposed above and parallel to the first mirror and forming with said first mirror an optical cavity that is perpendicular to the chip, the first
15 and second mirrors being distributed Bragg reflectors comprising a plurality of layers formed one on top of the other, and

 an active region surrounded by first and second spacers disposed between said mirror,
20 the uppermost layers of said second mirror

 forming a mesa having a diameter less than an inner diameter of the rim,

 each mesa being aligned to and engaging an optical fiber so as to place a substantial portion of
25 said mesa inside the rim of a fiber, and

 each laser emitting optical radiation that is substantially coupled into an optical fiber.

53. The interconnect of claim 52 further
30 comprising holding means for maintaining the relative positions between the coupling ends of said fiber array and said lasers.

54. The interconnect of claim 53 wherein
35 said holding means comprises epoxy applied to the exterior of the coupling ends and the lasers.

55. The interconnect of claim 53 wherein each laser further comprises a contact surrounding the mesa and formed on the layers of said second mirror that is close to the active region.

5 56. The interconnect of claim 53 wherein each fiber is a single mode fiber.

57. The interconnect of claim 53 wherein each fiber is a multi-mode fiber.
10

58. The interconnect of claim 53 wherein each mesa has a thickness of 1 to 3 μm .

59. The interconnect of claim 53 wherein each laser further comprises an annular implanted current confinement region surrounding the active region.
15

60. The interconnect of claim 53 further comprising guiding means disposed in said holder, and aligning means formed on said chip, said aligning means receiving said guiding means so as to mechanically align said array of lasers to said fiber array.
20

25 61. The interconnect of claim 60 wherein said guiding means comprises two guiding pins mounted in the holder, said pins extending through said first surface of the holder, and said aligning means including two aligning holes in said chip, the fiber array being aligned to the array of lasers by aligning and engaging said guiding pins with said aligning holes.
30

35 62. The interconnect of claim 53 wherein said fiber array and said array of lasers are two-

dimensional arrays having substantially the same pattern.

63. The interconnect of claim 53 wherein
said fiber array and said array of lasers are one-
5 dimensional arrays having substantially the same
pattern.

64. The interconnect of claim 6 wherein the
optoelectronic device array comprises a one-
10 dimensional array of super luminescence diodes, each
diode being axially aligned to a fiber and the fibers
receiving optical radiation emitted by the diodes.

65. The interconnect of claim 32 wherein
15 the array of optoelectronic devices comprises an one-
dimensional array of super luminescence diodes, each
diode being axially aligned to an end of a fiber and
the fibers receiving optical radiation emitted by the
diodes.

20

66. The interconnect of claim 55 wherein
each laser further comprises a substrate contact
disposed below the substrate.

25

30

35

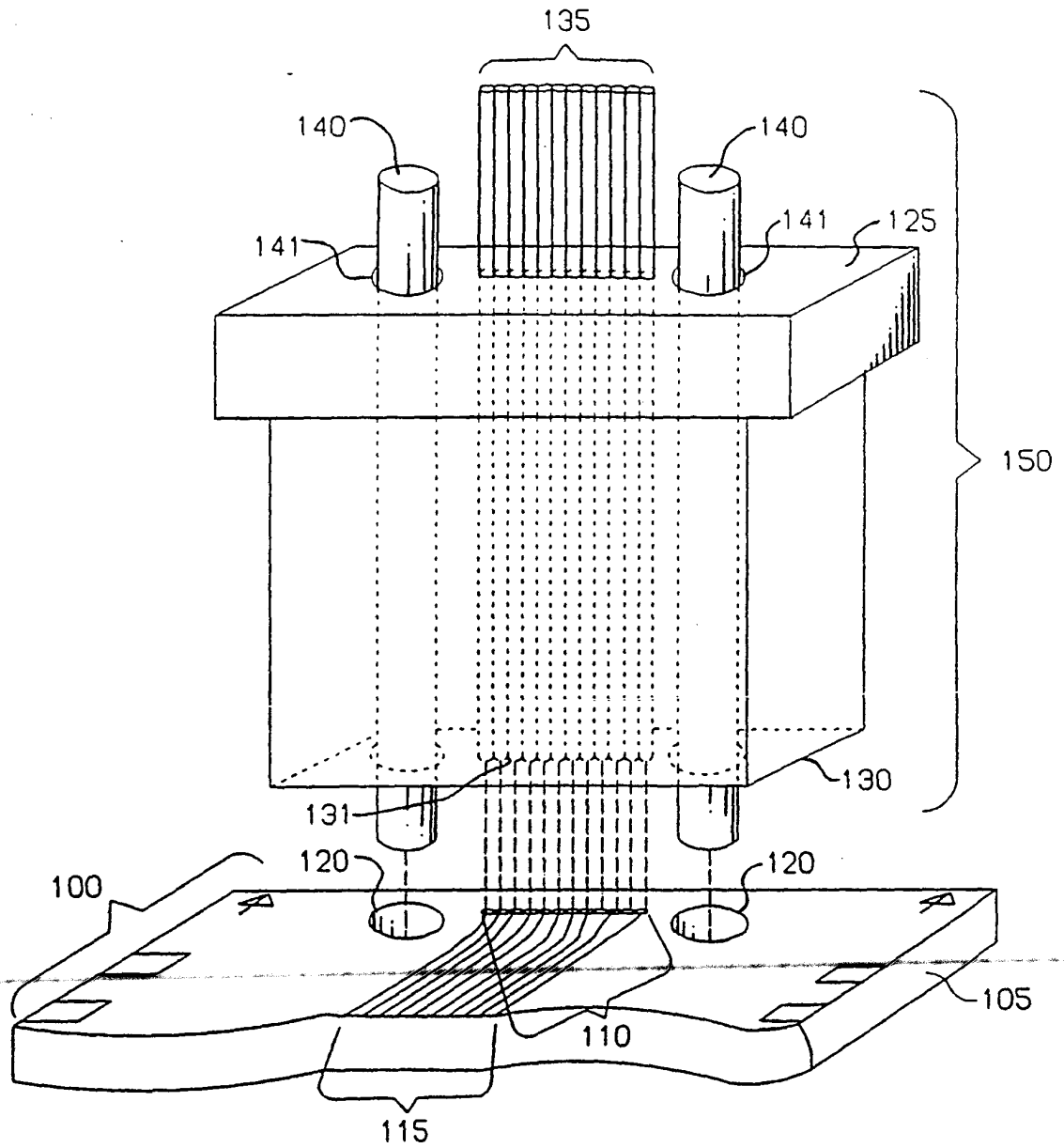


FIG. 1a

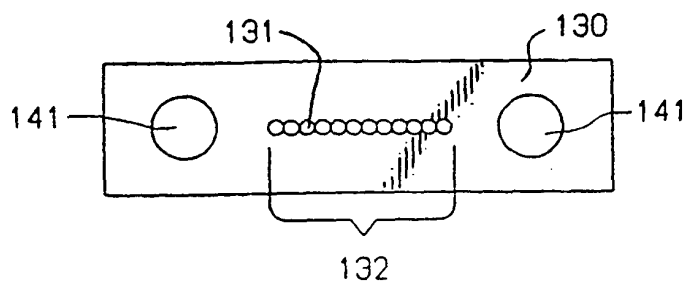
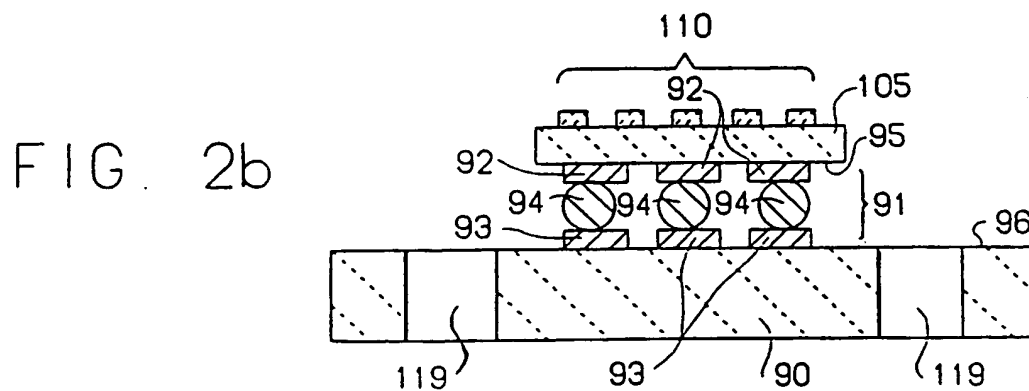
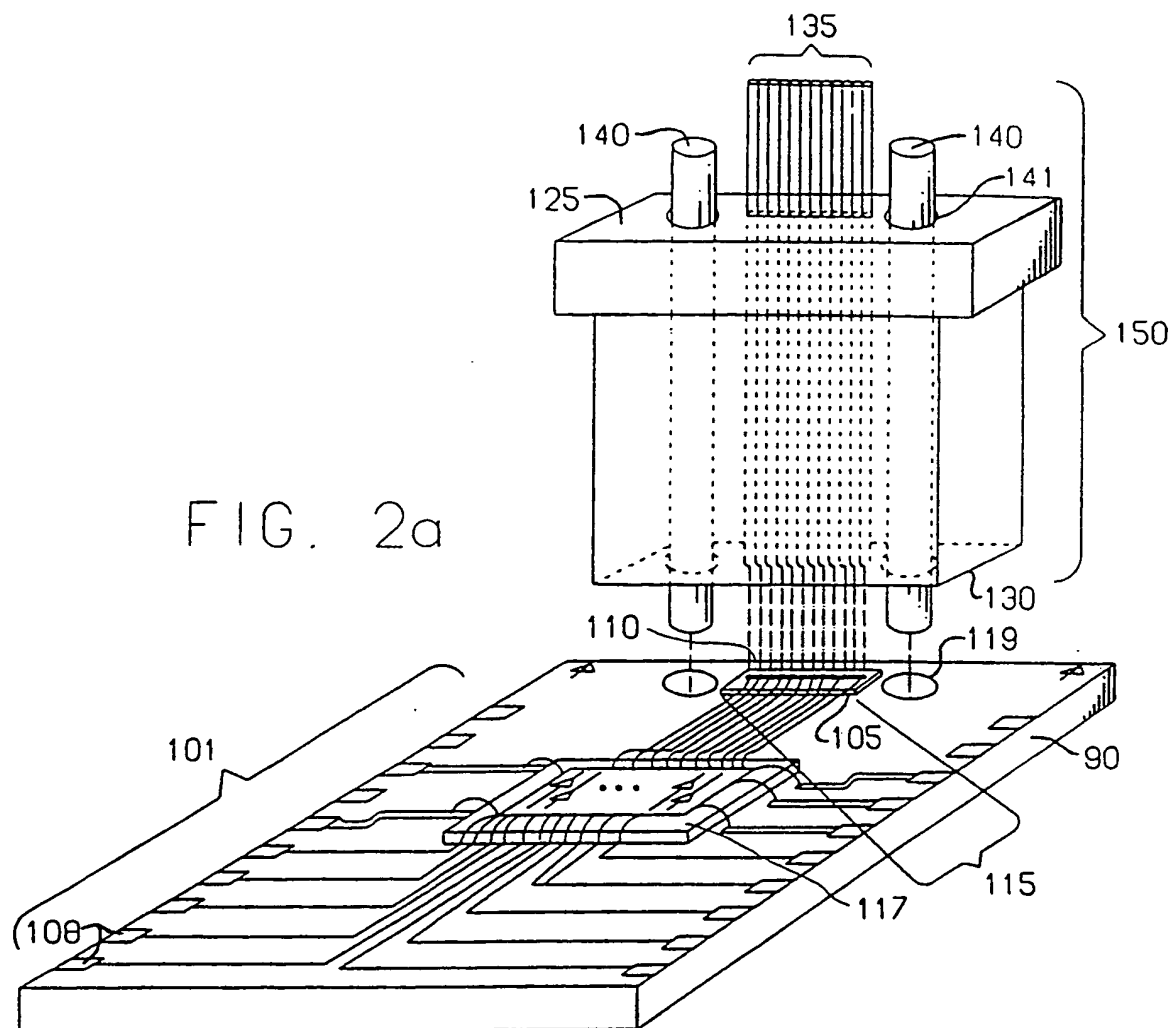


FIG. 1b



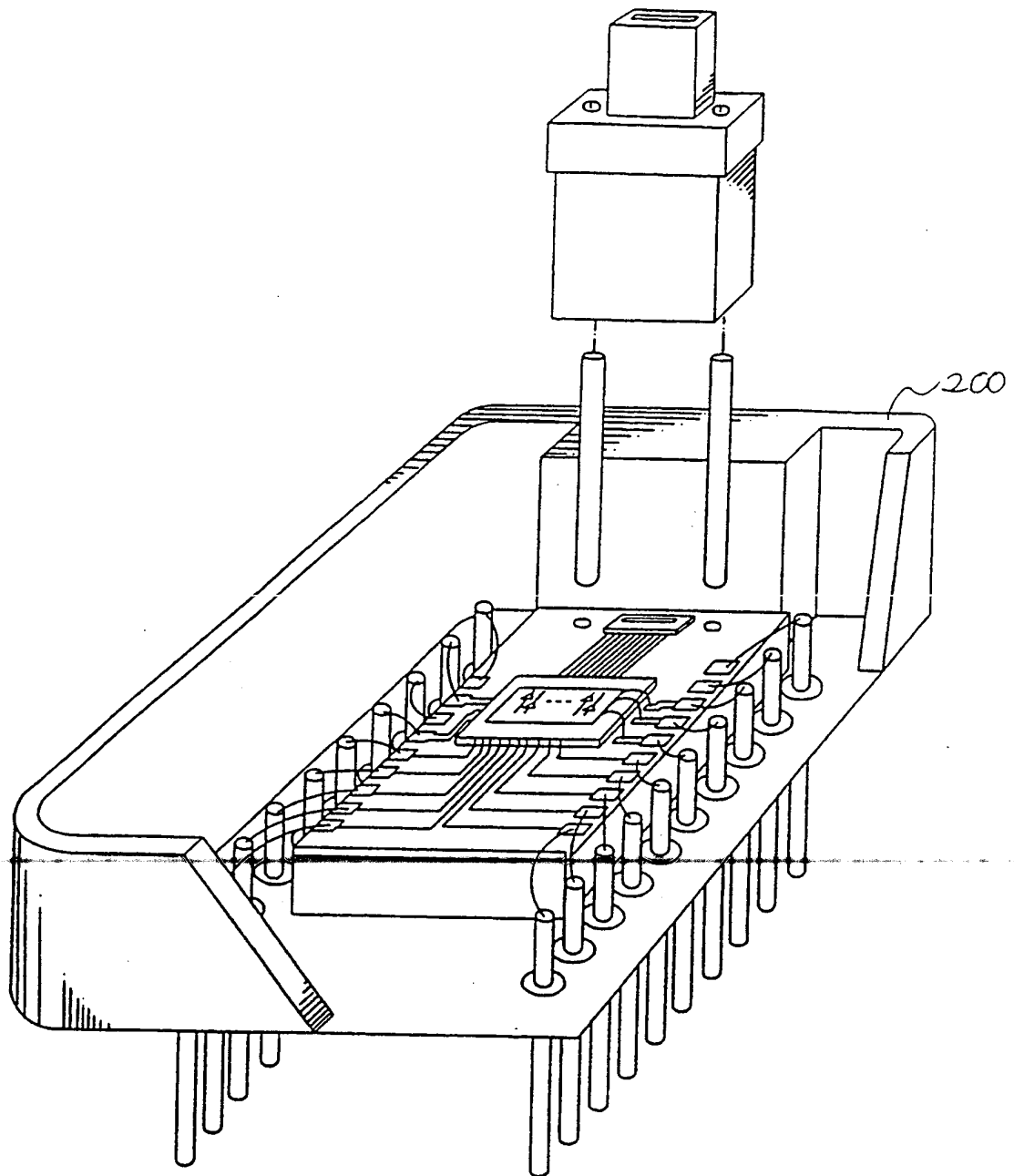


FIG. 3

3 / 7

SUBSTITUTE SHEET (RULE 26)

FIG. 4a

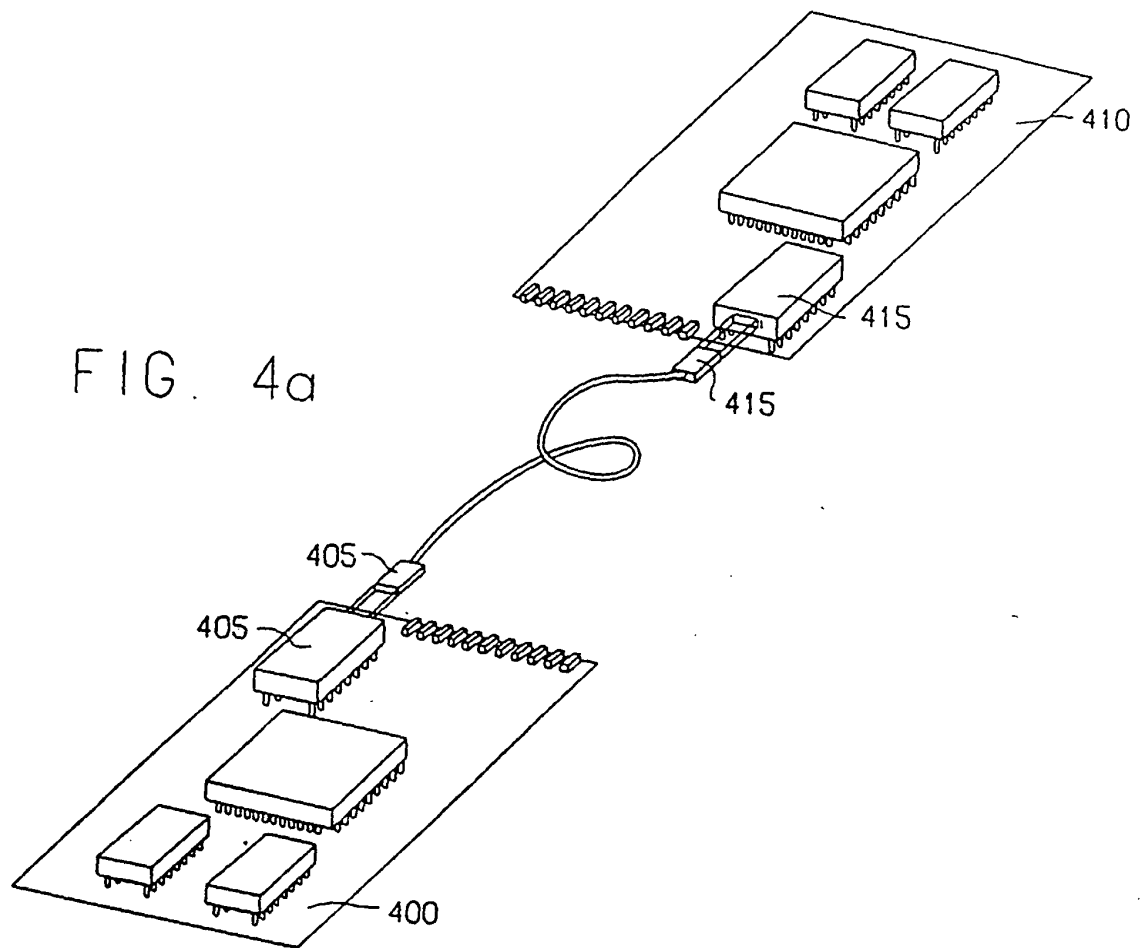
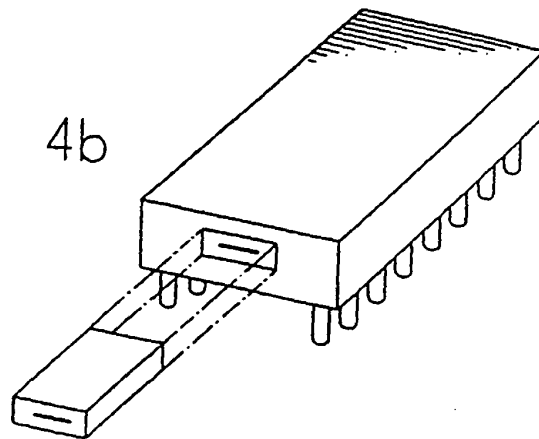


FIG. 4b



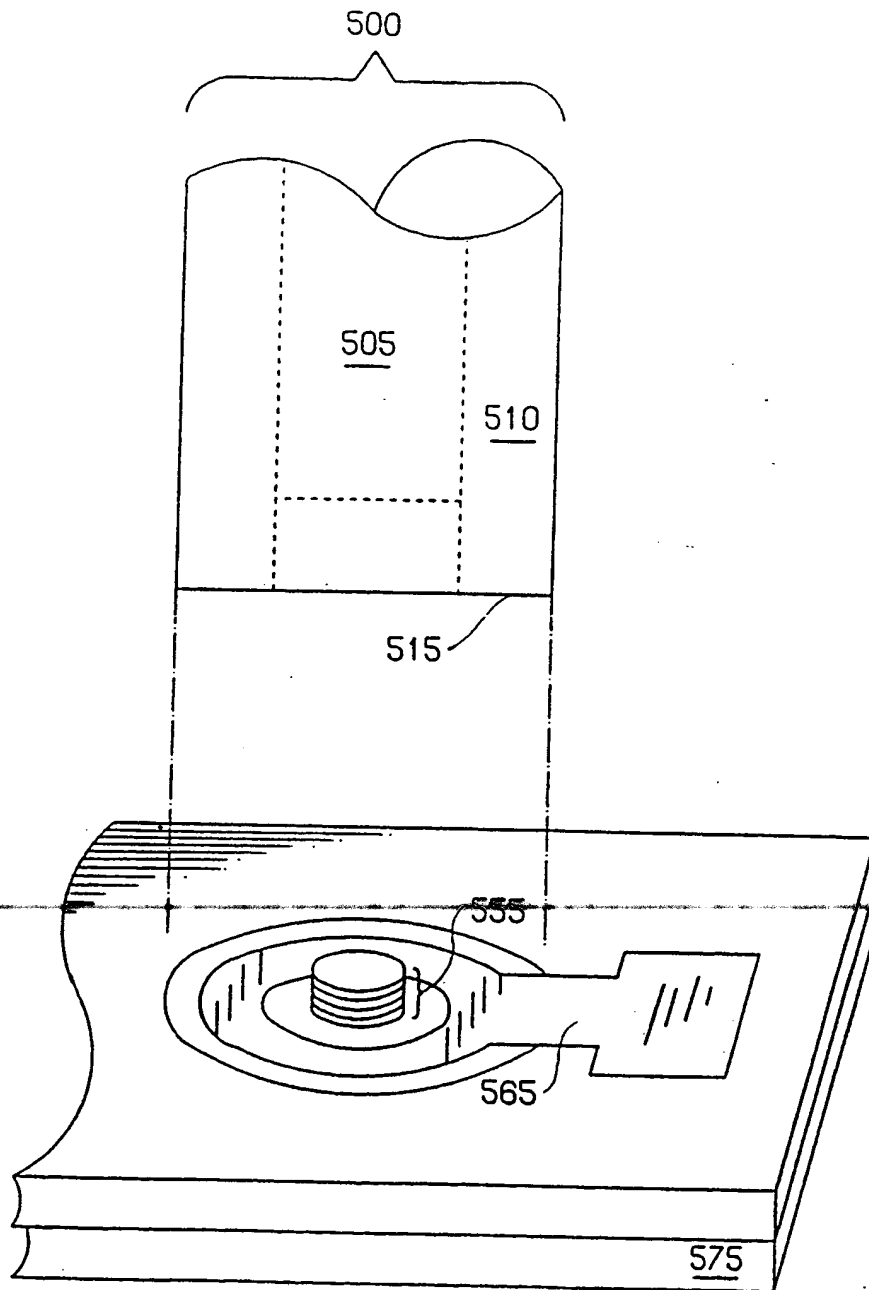


FIG. 5a

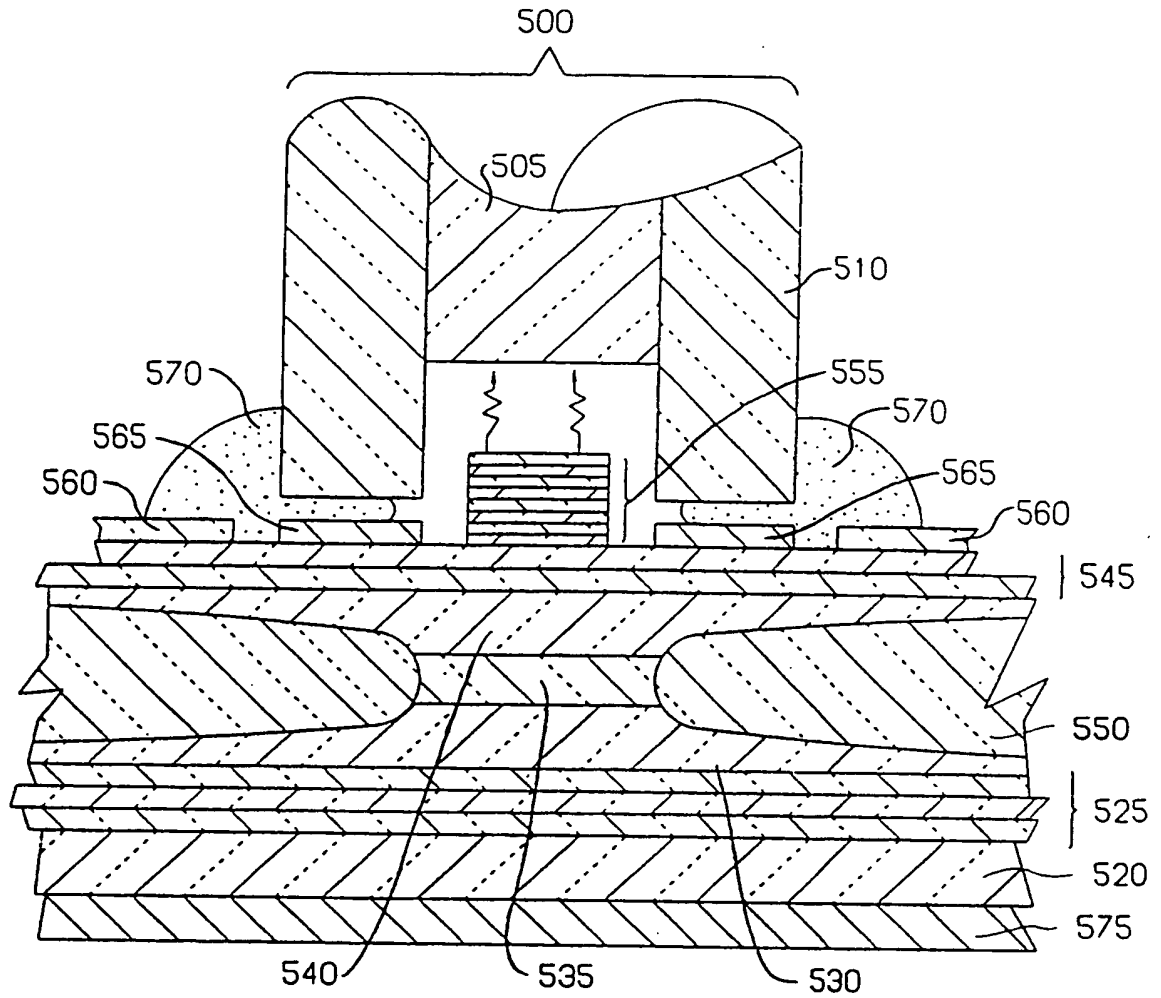


FIG. 5b

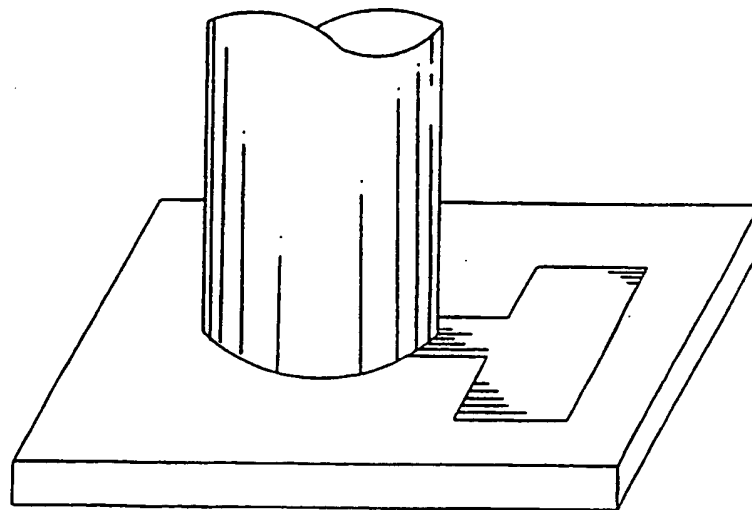


FIG. 5c

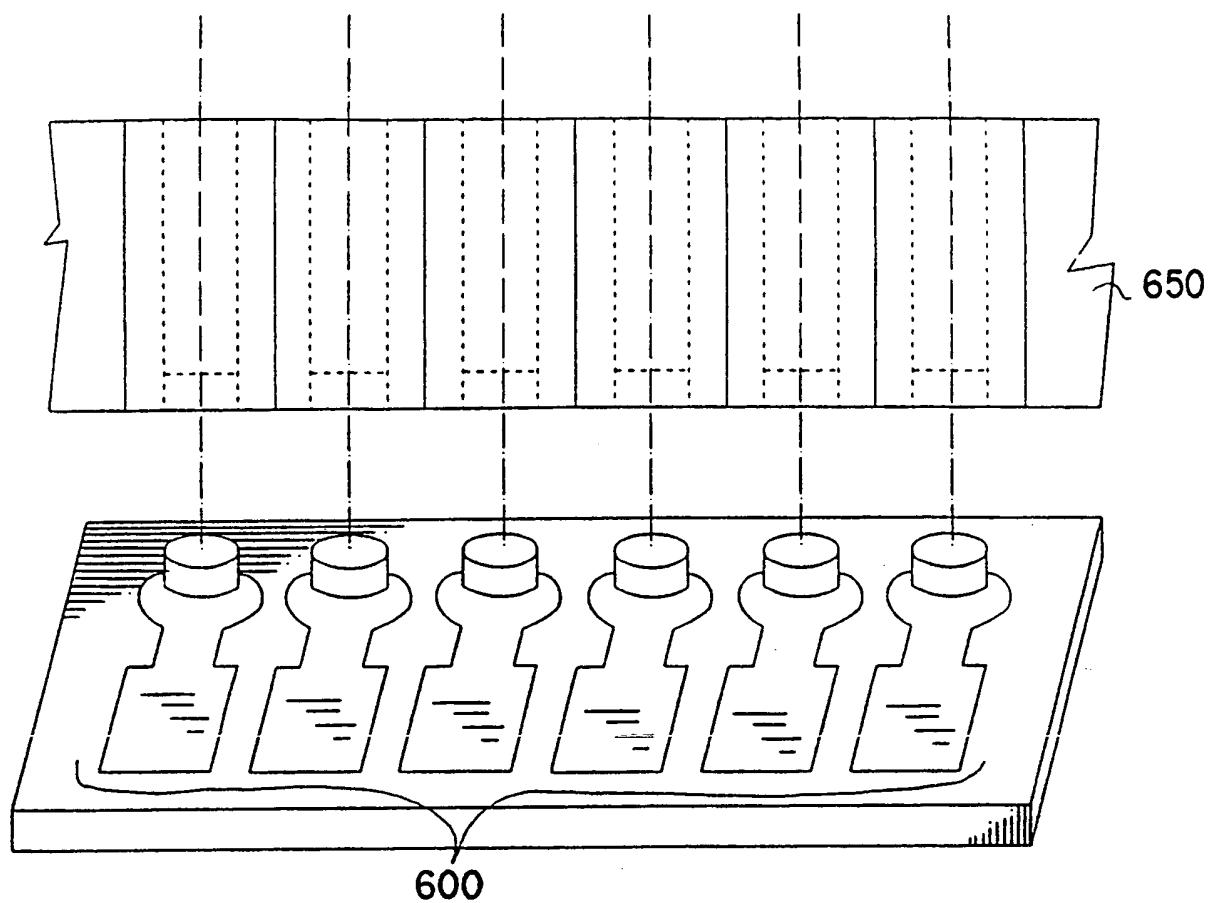


FIG. 6a

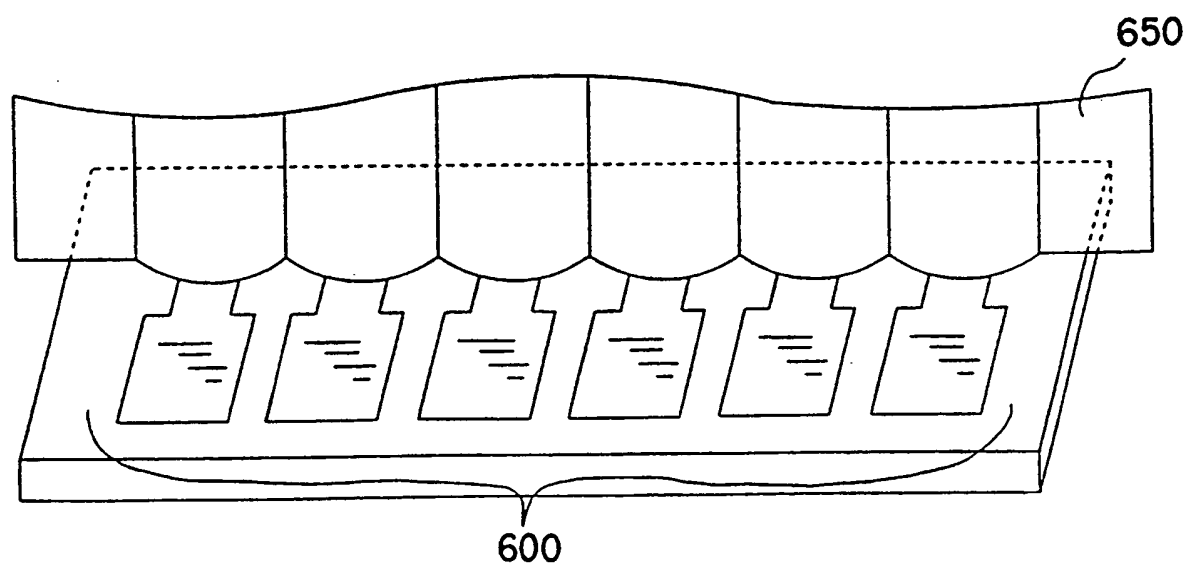


FIG. 6b

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/05749

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : GO2B 6/00, 6/12, 6/26, 6/36, 6/42; HOIL 39/02, 21/70; B29D 11/00

US CL : Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/ 14,38,88,89,90,91,92,93,94,126,131,132; 437/51,204,206,207,209,249; 264/1.5,1.7

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,155,786 (ECKER ET AL.) 13 OCTOBER 1992 SEE ABSTRACT	1-66
Y	US, A, 5,168,537(RAJASEKHARAN ET AL) 01 DECEMBER 1992, SEE ABSTRACT	1-66
Y, P	US, A, 5,230,030 (HARTMAN ET AL) 20 JULY 1993, SEE ABSTRACT	1-66
Y, P	US, A, 5,249,245 (LEBBY ET AL) 28 SEPTEMBER 1993, SEE ABSTRACT	1-66
Y, E	US, A, 5,337,391 (LEBBY) 09 AUGUST 1994, SEE ABSTRACT	1-66
Y, P	US, A, 5,309,537 (CHUN ET AL.) 03 MAY 1994, SEE ABSTRACT	1-66

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*G*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

07 SEPTEMBER 1994

Date of mailing of the international search report

11 3 SEP 1994

 Name and mailing address of the ISA/US
 Commissioner of Patents and Trademarks
 Box PCT
 Washington, D.C. 20231

Facsimile No. (703) 305-3594

Authorized officer

AKM E. ULLAH

Telephone No. (703) 308-4885

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/05749

A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

385/ 14,38,88,89,90,91,92,93,94,126,131,132; 437/51,204,206,207,209,249; 264/1.5,1.7

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

APS: OPTIC?(2A) (FIBER OR FIBRE)

ALIGN?

SUBSTRATE

OPTOELECTRONIC

BOARD

ARRAY